Racing Cylinders!

Demonstration

Participants will learn about how shape affects how objects roll. This is a great hands-on demonstration that can be used to teach about Newton's Laws of motion, moments of inertia, and mass on a wide range of understanding.

Number of Participants: 1-5

Audience: Elementary (ages 5-10) and up

Duration: 10-20 mins

Difficulty: Level 1

Materials Required:

- Cans of different varieties
    - e.g. chili, chicken noodle, empty, soda, seltzer, etc.
- A ball/sphere of roughly the same diameter as the cans
- A ramp/wooden board at least 1 meter long
- A stack of books, chair, or another way to create a stable incline
- A stopwatch, timer, or similar phone app that displays tenths of a second
- Optional: Other cylinders of varying sizes
- Optional: Blackboard/Whiteboard for illustrations and equations

Setup:

1. Stack the books and place the ramp or board to create an incline, as seen in Figure 1. Be prepared to catch rolling cans.

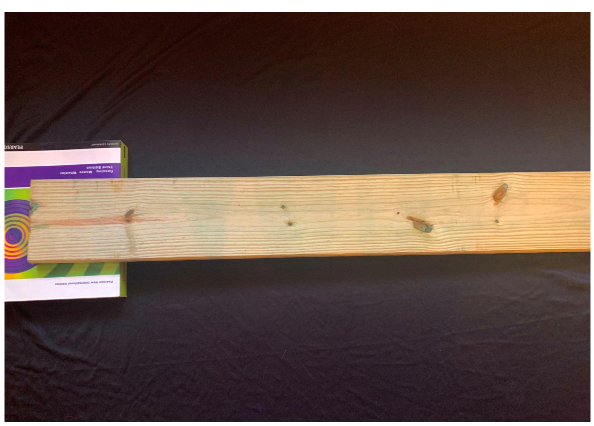

Figure 1: A board placed on a book to create an incline. An angle of 10-20^0 provides a reasonable time to measure for a board of ~1 m in length.

2. Have a discussion about what factors might influence how fast a can rolls down an incline. Write down all possible ideas.
3. Have students select what they think are the most important factors (such as weight, size, contents, etc.)
4. Have the participants each choose a can as their "race-can"
    a. For larger groups, split the participants into teams and have the teams choose a "race-can"
5. Assign 1 or 2 students to be the official timekeepers. Have the remaining students roll the cans down the ramp, racing each other.

    Set up a bracket system for the cans and have cans eliminated each round or race the cans individually to see who has the fastest time.

Presenter Brief:

The presenter should have a basic understanding of rotational physics and the concept of moment of inertia. The greater the moment of inertia, the slower the object will roll down a fixed incline. This is because more of the initial potential energy goes into rotational kinetic energy rather than translational kinetic energy. It is important to note that the contents of the cans matters, independent of mass, because of the potential for liquids to move in different ways (thick soups sticking versus chunky mixtures versus water). It is advised that you practice before running the demonstration.

Vocabulary:

- Moment of Inertia: a quantity that indicates an object's willingness to rotate, generally represented as I.
- Rotation: an object's movement through space by rotating around 1 or more axes.

Equations:

- $M = mass\ of\ the\ can$; $R = radius\ of\ the\ can$; $I = moment\ of\ inertia$
- Moment of Inertia for:
    - A solid cylinder: $I = \frac{1}{2}MR^2$
    - A hollow cylinder: $I = MR^2$
    - A solid sphere: $I = \frac{2}{5}MR^2$
- Energy Conservation for Rotation

- $mgh = \frac{1}{2}mv^2 + \frac{1}{2}I\omega^2$

  where $\omega = \frac{v}{R}$ is the rotational velocity (how fast the object is spinning)

- Using algebra, we can find the velocity at the bottom of the ramp for different objects. The greatest velocity will be the quickest.
- For a solid cylinder, $v_{sc} = \sqrt{\frac{4}{3}gh}$
- For a hollow cylinder (hoop), $v_{hc} = \sqrt{gh}$
- For a solid sphere, $v_{ss} = \sqrt{\frac{10}{7}gh}$
- As you can see, the mass and the radius of the sphere don't matter in an ideal system. Of course friction will play a role in the experiment, but it shouldn't be major.

Physics & Explanation:

Elementary (ages 5-10):

Have all the participants pick a "race-can" and then ask the students which race-can do they think will be the fastest. Ask them why they think it'll be fastest. A common answer may be based on the weight of the can. Entertain all the ideas, and then run the races. Before racing, make sure individual students make a prediction.

After the races have finished, have the timekeeper say which can was the fastest. The participants will realize that the cans that have soup in them are slower than the empty soup can, and if you use the sphere that will be the fastest. They will also realize that the full soup cans will be very close in time. You can use this to explain that the weight isn't important in the speed, only if they're full or not. Briefly mention how there is translational energy and rotational energy. Explain that the water inside the can is not being spun around by the edges very much, so more energy can go into moving it down the ramp.

🔑 The shape and contents of the can affect how fast it will roll down the ramp.

Optional: After the races, you can use the cylinders of varying sizes to explain that the size of the cylinder also isn't important, and again it is just whether it is full or not.

Middle (ages 11-13) and general public:

Ask the participants what they know about inertia (not rotational). You may get a variety of answers, but make sure they all understand that at its core, inertia is the willingness of an object to move or how much effort you have to exert to get an object to move. **Ask them if they think rotating objects also have an inertia to get them**

spinning. Guide them to the term moment of inertia being the willingness of an object to rotate.

Have all the participants pick a "race-can" and then ask them which race-can do they think will be the fastest. Ask them why they think it'll be fastest. A common answer may be based on the weight of the can. Entertain all the ideas, and then run the races.

After the races are finished, review who had the fastest time. The participants will realize that the cans that have soup in them are faster than the empty soup can, and if you use the sphere that will be the fastest. **Ask the participants which cans they think have the highest moment of inertia.** This may result in a variety of answers, and the question is somewhat of a trick question. If the masses were all the same, the hollow can would have the highest, but since mass plays a part in the moment of inertia this becomes tricky to determine. You can use this question to demonstrate that the velocity depends on the shape of the object, and not the mass or the size.

Feel free to give the equations for the moment of inertia if your participants understand some basic algebra, but it isn't necessary for this group.

The speed at which the can rolls down depends on rotational inertia of the can.

Optional: After the races, you can use the cylinders of varying sizes to explain that the size of the cylinder also isn't important, and again it is just whether it is full or not.

High School (ages 14+):

Ask the participants what they know about inertia (not rotational). You may get a variety of answers, but make sure they all understand that at its core, inertia is the willingness of an object to move or how much effort you have to exert to get an object to move. **Ask them if they think rotating objects also have an inertia to get them spinning.** Guide them to the term moment of inertia being the willingness of an object to rotate.

Have all the participants pick a "race-can" and then ask them which race-can do they think will be the fastest. Ask them why they think it'll be fastest. A common answer may be based on the weight of the can. Entertain all the ideas, and then run the races.

After the races are finished, review who had the fastest time. The participants will realize that the cans that have soup in them are faster than the empty soup can, and if you use the sphere that will be the fastest. **Ask the participants which cans they think have the highest moment of inertia.** This may result in a variety of answers, and the question is somewhat of a trick question. If the masses were all the same, the hollow can would have the highest, but since mass plays a part in the moment of inertia this becomes tricky to determine. You can use this question to demonstrate that the velocity depends on the shape of the object, and not the mass or the size.

You can explain this phenomenon in terms of energy conservation, and if you have a blackboard you could even do the proof. Essentially, the greater the coefficient in front of MR^2, the more of the potential energy gets turned into rotational kinetic energy rather than translational kinetic energy.

Feel free to give the equations for the moment of inertia and explain how for equal masses and sizes, the moment of inertia for the hollow cylinder is the largest, but make sure to mention again that in the experiment mass and size don't matter, hence it just leaves the coefficient in front of the MR^2 as the indicator to which is the slowest.

🔑 The speed at which the can rolls down depends on rotational inertia of the can as well as how much rotational vs translational kinetic energy there is.

Optional: After the races, you can use the cylinders of varying sizes to explain that the size of the cylinder also isn't important, and again it is just whether it is full or not.

Additional Resources:

- The math on moment of inertia: http://hyperphysics.phy-astr.gsu.edu/hbase/mi.html
- Rotational Inertia: The Race Between a Ring and a Disc: https://www.youtube.com/watch?v=CHQOctEvtTY
- Khan Academy Moment of Inertia: https://www.khanacademy.org/science/physics/torque-angular-momentum/torque-tutorial/v/more-on-moment-of-inertia
- Video on Rotational Inertia: https://www.youtube.com/watch?v=W9fPGXyvrVM&ab_channel=BozemanScience

References:

1. Proof for equations section: http://hyperphysics.phy-astr.gsu.edu/hbase/hoocyl.html